TECHNICAL REPORT

ISO TR 7705

Second edition
1991-11-15

Guidelines for specifying Charpy V-notch impact prescriptions in steel specifications

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Directives pour la spécification des prescriptions d'énergie de rupture sur éprouvette Charpy à entaille en V dans les normes d'acier

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Reference number
ISO/TR 7705:1991(E)

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The main task of technical committees is to prepare International Standards, but in exceptional circumstances a technical committee may propose the publication of a Technical Report of one of the following types:

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— type 1, when the required support cannot be obtained for the publication of an International Standard, despite repeated efforts;

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— type 2, when the subject is still under technical development or where for any other reason there is the future but not immediate possibility of an agreement on an International Standard;

— type 3, when a technical committee has collected data of a different kind from that which is normally published as an International Standard ("state of the art", for example).

Technical Reports of types 1 and 2 are subject to review within three years of publication, to decide whether they can be transformed into International Standards. Technical Reports of type 3 do not necessarily have to be reviewed until the data they provide are considered to be no longer valid or useful.

ISO/TR 7705, which is a Technical Report of type 2, was prepared by Technical Committee ISO/TC 17, *Steel*.

This second edition cancels and replaces the first edition (ISO/TR 7705:1983), which has been technically revised.

The Charpy V-notch impact test is widely used as a means of evaluating the toughness and the susceptibility to brittle fracture of steel products. It is also considered to be suitable for checking the soundness of a material.

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International Organization for Standardization
Case Postale 56 • CH-1211 Genève 20 • Switzerland

Printed in Switzerland

Therefore, the Charpy V-notch impact test is included in many ISO standards developed by sub-committees of ISO/TC 17 responsible for standardization of steel products.

ISO/TR 7705 was published in 1983 with a view to giving recommendations for specifying impact strength requirements in ISO standards for steel products, when those requirements were still being considered.

At the time of the three-yearly review in 1986 it was decided by a majority of TC 17 P-members that ISO/TR 7705 be revised and remain as a Technical Report, taking into account the comments received.

Annex A forms an integral part of this Technical Report.

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Guidelines for specifying Charpy V-notch impact prescriptions in steel specifications

1 Scope

This Technical Report gives recommendations for specifying Charpy impact V-notch prescriptions in steel specifications.

Extracts from ISO 148, ISO 404, ISO/R 442 and ISO 3785 listed in clause 2 are given in annex A.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this Technical Report. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this Technical Report are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 148:1983, *Steel — Charpy impact test (V-notch).*

ISO 404:1981, *Steel and steel products — General technical delivery requirements.*

ISO/R 442:1965, *Verification of pendulum impact testing machines for testing steels.*

ISO 630:1980, *Structural steels.*

ISO 683-1:1987, *Heat-treatable steels, alloy steels and free-cutting steels — Part 1: Direct-hardening unalloyed and low-alloyed wrought steel in form of different black products.*

ISO 2604-4:1975, *Steel products for pressure purposes — Quality requirements — Part 4: Plates.*

ISO 3785:1976, *Steel — Designation of test piece axes.*

ISO 4950-2:1981, *High yield strength flat steel products — Part 2: Products supplied in the normalized or controlled rolled condition.*

ISO 4950-3:1981, *High yield strength flat steel products — Part 3: Products supplied in the heat- treated (quenched + tempered) condition.*

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3 General feature of Charpy V-notch impact test

3.1 Toughness testing methods in design codes and in steel specifications

Tests for evaluating the toughness of steel can be divided into two categories: notch toughness tests and fracture toughness tests based on fracture mechanics.

Notch toughness tests are used to measure the ability of a material to absorb energy and deform plastically in the presence of a mechanical notch. The Charpy V-notch impact test and the drop weight test are typical examples of small scale tests which are used for evaluations of notch toughness. They are often used to determine the ductile to brittle transition temperature of a material and to give a qualitative estimate of the material's toughness. Due to relatively good reproducibility and cheapness these methods are highly suitable for use as delivery tests for steel consignments.

Fracture toughness tests such as the CTOD test are fracture mechanics tests which are generally concerned with the determination of critical crack sizes which can appear without causing fracture in a material loaded to a specific stress level. Fracture mechanics tests are very complicated and expensive to carry out. They are primarily used to examine the behaviour of the material in a structure with respect to safety rules etc. Therefore, fracture mechanics testing is primarily connected with design codes and not with steel specifications.

For these reasons, only notch toughness tests are dealt with in these guidelines for steel specifications.

3.2 Historical background to the Charpy V-notch impact test

When welded structures, especially heavy ones such as bridges and ships, were developed on an industrial scale, and especially when the fabrication methods called for joining heavy segments by welding, problems with brittle fractures became more common. This was specially evident during the second world war when the USA began to produce welded ships of the Liberty and Victory type, where a lot of failures occurred due to brittle fractures.

An empirical relationship based on many tests was found between the Charpy V-notch impact energy and service fractures. What was started in the USA was then continued by IIW (International Institute of Welding) with their recommendations and classification system for steels according to their susceptibility to brittle fracture after welding.

Originally the USA required an impact energy value of 15 footpounds (ft·lb) for a standard 10 mm × 10 mm V-notch impact test piece which was later increased to 20 ft·lb. The IIW recommendation converted these figures into metric units and referred the impact energy value to the cross-section under the notch which gave a figure of 3,5 kg·m/cm^2 corresponding to 20 ft·lb. Later the units were transformed into SI units and the reference to the area was retained. This gave the value of 27 J (20 ft·lb).

Today 27 J is generally used for mild carbon and carbon-manganese steels and 40 J (30 ft·lb) for steels with higher tensile properties.

3.3 The Charpy V-notch impact test in relation to other tests

Originally the Charpy impact test was performed with a "keyhole" or U-notch test bar. Its purpose was to check that the material was sound as to cleanliness, rolling and heat treatment. In the 1950's interest was concentrated on the risk of brittle fracture in welded structures and the V-notch test bar was introduced because the V-notch test indicates transition behaviour more clearly than the U-notch test.

In addition to the Charpy impact test other impact test methods (e.g. Mesnager, Izod, Schnadt etc.) have also been used.

The drop weight test is a material test which is intended to measure the highest temperature at which a steel exhibits brittle fracture. Some offshore material standards allow the acceptance of plate material for offshore applications on the basis of drop weight testing but normally this test is used for information purposes only. This test may be an alternative to the Charpy V-notch impact test.

In 1953 Pellini compared the Charpy V-notch impact test with an explosion crack starter test intended to simulate the service performance of higher quality steels. Pellini recommended an impact energy of 20 ft·lb (27 J) instead of the earlier used 15 ft·lb.

Wells also simulated service conditions at the starting point of a brittle fracture crack by using a wide plate test. The intention of this test, which of course could not be used as a delivery test for a steel consignment, was to include in a big plate specimen the stresses existing in a weld, the influence of plate thickness, the type of defect etc. The results of wide plate tests were also compared with Charpy V-notch impact values.

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3.4 Factors influencing impact properties

The behaviour of a steel structure subject to impact is not only dependent on the material. It is also dependent on the following:

— material thickness;

— stress state;

— temperature;

— steel type;

— loading rate;

— surface conditions;

— residual stresses;

— yield strength.

In addition, the Charpy V-notch test result is influenced by the following:

— orientation of test piece;

— orientation of notch;

— sharpness of notch;

— specimen position in the product;

— steel type;

— type of impact machine striker.

For these and other reasons (e.g. different safety potentials) the impact energies or transition temperatures determined under the well-defined conditions of an impact test cannot without any further considerations be regarded as determinant with respect to temperature and/or thickness for the application of the material.

3.5 The Charpy V-notch impact test as a powerful tool for delivery control in steel specifications

The Charpy V-notch impact test can be used as a means of expressing the toughness and the susceptibility to brittle fracture in a steel specification. It is a cheap and easily reproducible test method which is empirically related to the susceptibility to brittle fracture and therefore to the weldability of a steel. It is also a way to check the soundness of a material as far as heat treatment and tensile properties are concerned.

Therefore, impact test requirements are included in many ISO steel specifications. The aim of this technical report is to give guidelines for specifying Charpy V-notch impact requirements in steel specifications. It is not intended to force upon the different sub-committees of ISO/TC 17 what they should include in their steel specifications, but if impact test requirements are included, this recommendation should be taken into consideration, to ensure a consistent philosophy within ISO/TC 17.

4 Information to be gained from the impact test

Independent of the size of the test piece, the thickness of the material and the type of notch, the impact test carried out for a specified material of given thickness at different temperatures gives a curve (except for austenitic steels) absorbed energy KV versus temperature (see figure 1). This curve may be separated into three parts; one part at higher temperatures and higher energies (upper shelf), one part at lower temperatures and lower energies (lower shelf) and a transition range in between. The scatter of results on the upper and lower shelves is relatively small but the scatter in the transition part of the curve is relatively large. Because of this scatter, the method of testing three test pieces and taking the mean value was chosen.

Austenitic stainless steels are also ductile at very low temperatures, and consequently the impact curve is on the upper shelf even at very low temperatures (see figure 2).

Since the test result depends upon the geometry of the test piece, the thickness etc., the test is carried out on a standardized test bar (10 mm × 10 mm, 7,5 mm × 10 mm, 5 mm × 10 mm) and reduced test bar with a thickness equal to the product thickness [see 6.4 c)] and it is irrelevant to refer the impact energy to a cross-sectional area. The energy level should therefore be given in joules only.

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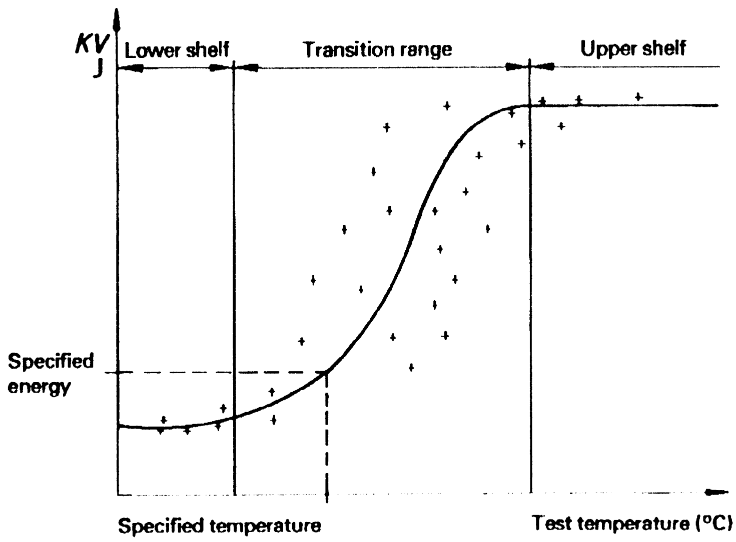

Figure 1

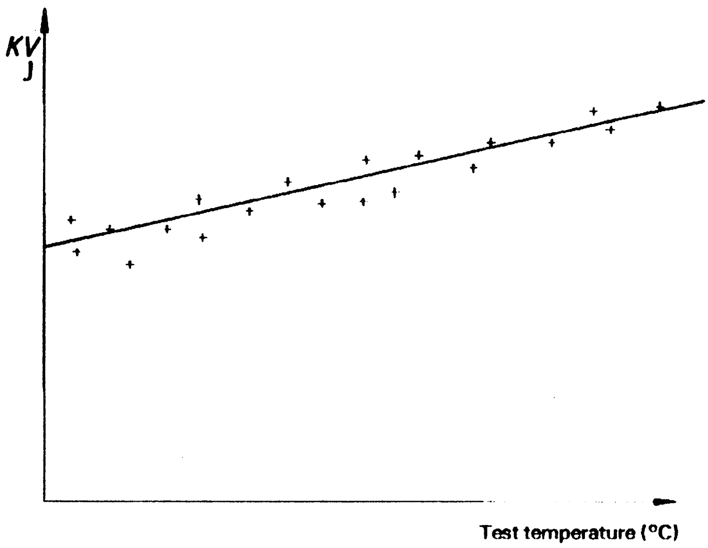

Figure 2

The impact test is prescribed in material specifications for the following two reasons.

a) To check indirectly whether the steel is sound with reference to cleanliness, manufacturing process, heat treatment etc.

   The test in this case is normally carried out at room temperature and the impact energy level is of importance.

b) To classify a steel according to its susceptibility to brittle fractures.

   In this case the result of interest is whether the test reaches the upper or the lower shelf of the curve and, especially, where the transition range is located on the temperature scale. If the test result corresponds to the upper part of the curve, the conclusion can be drawn that the toughness of the material is considerably better than if the result corresponds to the lower part of the curve. Furthermore, if the transition range of the curve for one steel occurs at a considerably lower temperature than that for another steel, impact test results for the first steel will lie on the upper part of the curve at lower temperatures than for the other steel and hence the conclusion can be drawn that the first steel has a better toughness and is more suitable for constructions that are fabricated and/or used at lower temperatures.

The most important information obtained is therefore the temperature range where the change from ductile to brittle fracture occurs i.e. the transition temperature. From the normal impact energy-temperature curves it has been found that an impact energy of 27 J is suitable for determining the transition temperature. For fine-grain steels with elevated yield stress properties (high tensile steels), a higher level may be justified.

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Other information from the test can also be of importance, such as the fracture appearance and lateral expansion measured after fracture.

It should be observed that as the impact energy is not a material property, a high value only indicates a tougher material, when the comparison is made with the same material having the same thickness and the test is carried out with the same size of test pieces at the same temperature.

5 Subsize test pieces

The standard V-notch test piece, has a cross-section of 10 mm × 10 mm.

As the test pieces must be machined to a good surface finish, it is not possible to take 10 mm × 10 mm test pieces from plates thinner than 12 mm or from round bars with a diameter of less than 16 mm. Especially for plates, customers often require impact tests on material with thickness < 12 mm and therefore two subsize V-notch test pieces have been standardized, viz. 5 mm × 10 mm and 7,5 mm × 10 mm.

When testing a material with subsize test pieces (see figure 3), it has to be realized that

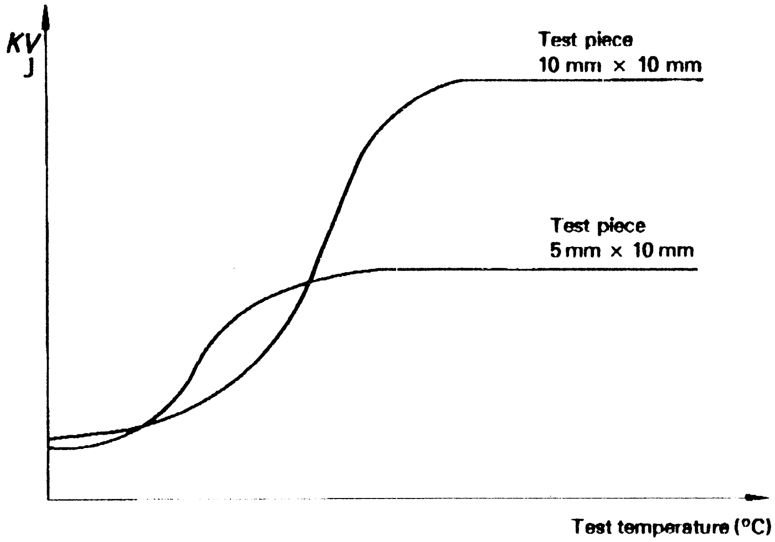

Figure 3

a) the transition range moves downwards to lower temperatures compared with the ordinary 10 mm × 10 mm test pieces;

b) the upper energy level is reduced compared to the ordinary 10 mm × 10 mm test piece.

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Furthermore, there is no simple mathematical connection between the test results obtained from 10 mm × 10 mm test pieces and those from subsize test pieces. Therefore, rules to reduce the impact values for subsize test pieces in relation to the values for ordinary test pieces are scientifically doubtful but are accepted for practical reasons.

The following should however be observed.

a) The difference between a correct reduced impact energy and an energy related to the reduction in thickness is very small in comparison to the normal scatter. In the case of the 7,5 mm thick test piece the 75 % value becomes 80 % which means, referred to a minimum value of 27 J for the normal test piece, a difference of 1,4 J.

b) Except for the temperature range at a high energy level, no simple formula for the dependency of the impact energy from the test piece thickness exists for the transition range. This means that the calculation of the minimum energy values for the subsize test pieces as a proportional function of the test piece thickness is a simplification.

c) With decreasing product thickness, the danger of brittle fracture decreases under otherwise comparable conditions, so that the calculation with 75 % and 50 %, instead of for example 80 % and 60 %, will not be critical.

6 Recommendations of ISO/TC 17/WG 15 for specifying impact strength requirements in steel specifications

6.1 Structural steels (ISO 630, ISO 4950-2, ISO 4950-3)

For carbon or carbon-manganese steels and normalized or quenched and tempered fine grain structural steels, the steels should be classified in terms of a temperature selected from one of the following: + 20 °C, 0 °C, − 20 °C, − 40 °C, at which a given minimum value of absorbed energy can be obtained. This value should be 27 J or alternatively in the case of steels with higher yield or tensile strength (R_e min. = 355 N/mm^2) 40 J. These values relate to the Charpy V-notch test made in the longitudinal direction irrespective of product form (see table 1).

Table 1 — Recommendations for grade — energy — test temperature combinations for Charpy V-notch requirements in steel specifications

Application		Structural purposes					Pressure purposes: RT or ET grades except fine grain steels	Pressure purposes: a) RT or ET grades of fine grain steels; b) LT grades										Engineering (machinery) purposes
Test piece direction 1)		longitudinal					transverse, where possible (see 6.2)											longitudinal
Recommended impact energy level for	longitudinal test pieces	27 2)					(x) 3)	(40)									(x)	x
	transverse test pieces	—					y 3)	27 2)									y	—
Preferred testing temperature (°C)		+20	0°	−20	−40	−60	+20	0°	−20	−40	−60	−80	−100	−120	−160	−196	−196	+20
Examples for concerned steel groups		C, CMn	fine grain steels, quenched and tempered steels				C, CMn, Mo/CrMo steels	fine grain steels RT and ET grades; fine grain steels LT grades			Ni steels						austenitic steels	steels for quenching and tempering, case hardening steels

1) In the case of tubes transverse (longitudinal) means that the longitudinal axis of the testpiece is transverse (parallel) to the longitudinal axis of the tube. In all other cases, it means that the longitudinal axis of the testpiece is transverse (parallel) to the direction of principal grain flow. In the case of rolled products, the direction of principal grain flow corresponds to the direction of final rolling. See also ISO 3785.

2) For higher strength steels, a higher energy value of 40 J may be appropriate.

3) The letters x and y indicate that the impact energy levels are to be considered by the relevant materials subcommittee. Brackets indicate "not preferred orientation".

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6.2 Steels for pressure purposes or for storage and transportation of liquefied gases (ISO 2604-4)

These steels should be tested using, if possible, specimens prepared from the transverse direction. If this is not possible, for instance for tubes, tests in the longitudinal direction are accepted. Recommended values are included in table 1.

6.3 Steels for engineering purposes (ISO 683-1)

For quenched and tempered engineering steels, an impact test at room temperature is often required to check the heat treatment.

The impact value should be specified in terms of a longitudinal Charpy V-notch test at room temperature. The actual value will differ according to the steel quality and should be agreed by the relevant product committee.

6.4 Subsize test pieces

For material thickness where the standardized test piece of 10 mm × 10 mm cannot be used, i.e. plates thinner than 12 mm and round bars with a diameter less than 16 mm, the following rules should apply.

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a) The standardized subsize test pieces of 7,5 mm × 10 mm and 5 mm × 10 mm should be used wherever possible. The test piece should be of the maximum standard size that can be obtained consistent with removing the scale from the surface.

b) Guaranteed values included in steel specifications should refer to tests with the standardized test piece of 10 mm × 10 mm.

c) For plates and tubes with thicknesses of 5 mm to 10 mm, it is normal practice to use subsize test pieces with a thickness equal to the product thickness. However, in cases of dispute only test pieces of 7,5 mm × 10 mm and 5 mm × 10 mm should be used.

d) For practical reasons guaranteed impact values in steel specifications for standardized subsize test pieces should be 75 % of the full-size test piece value for the 7,5 mm × 10 mm test piece and 50 % of the full-size piece value for the 5 mm × 10 mm test piece.

For test pieces according to c), the values should be obtained by linear interpolation.

6.5 Selection and preparation of samples and test pieces

6.5.1 Selection and preparation of samples

Apart from machining, the sample shall not undergo any processing or treatment.

6.5.2 Cutting and machining

Cutting shall be carried out cold taking precautions to avoid superficial work hardening and overheating of the steel which may change the mechanical characteristics.

After machining, any marks left by the tool which might interfere with the results of the test shall be removed, either by grinding (with ample coolant supply) or by polishing, provided that the method of finishing chosen maintains the dimensions and shape of the test piece within the tolerances stipulated in the standard for the appropriate test.

The tolerances of the dimensions of the test pieces shall be as stipulated in the appropriate standards for the test methods.

6.6 Number of test pieces to be taken per sample and specific requirements

The average value of three test pieces shall meet the specified requirement. One individual value may be below the specified value, provided that it is not less than 70 % of that value.

6.7 Location of test pieces

Impact test pieces shall be located in flat and round products according to table 2 and table 3.

6.8 Interpretation of test results

For invalidation of test and re-tests, reference is made to ISO 404 (see A.4).